A HOME INTERVENTION AUGMENTED REALITY TOOL FOR OCCUPATIONAL THERAPISTS

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HOMEMODAR: A HOME INTERVENTION AUGMENTED REALITY TOOL FOR OCCUPATIONAL THERAPISTS

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LIST OF SYMBOLS AND ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
AT	Assistive Technology
AR	Augmented Reality
CAD	Computer Aided Design
OT	Occupational Therapist
OTR/L	Occupational Therapist Registered/Licensed
PwID	People with Physical Impairments or Disabilities
QR Code	Quick Response Code
SDK	Software Development Kit
UI	User Interface
UX	User Experience

SUMMARY

The purpose of this project is to design a tablet-based AR application for use by OTs in home care. This application would allow OTs to support individuals with physical impairment and disability when making home modifications. Specifically, OTs would be able to search and show ATs for individuals to purchase and install to compensate for their reduced abilities and maintain independent living. The main purpose of this project includes enabling the OTs and their clients (PwIDs) to envision the most appropriate scenarios when purchasing and utilizing ATs in the home.

Several research methods have been employed to inform and evaluate the AR design as follows: 1) literature review of related studies on assistive technology and augmented reality, 2) semi-structured interviews to understand current challenges in home modifications of people with disabilities, 3) participatory workshops to codesign an AR prototype with the OTs and PwIDs, 4) prototyping the AR tool following an iterative process, and 5) user study to evaluate the product satisfaction with OTs.

Our user study revealed the potential of AR to include the home environment context when considering ATs and increase the involvement of PwIDs to make the process people-focused, both of which could result in an increase of buy-in from PwIDs and a decrease of AT abandonment.

CHAPTER 1. INTRODUCTION

The purpose of this project is to design an AR tool for the home modification process. This tool would allow OTs to search and show ATs. Specifically, OTs would be able to use their phone or tablet device to superimpose 3D models of ATs onto the real-world environments of the PwIDs' homes therefore visualize the looks and fits of the ATs.

1.1 Problem Statement

OTs help PwIDs to maximize their independence in daily activities through patient-centered interventions. In particular, home care OTs visit PwIDs in their homes to assess their living conditions and to recommend home modifications and adaptations that will create safe, supportive, and healing environments through using appropriate ATs (e.g., handrails, grab bars, and digital home assistance). However, the process of finding and purchasing compatible ATs for PwIDs' homes necessitates considering several factors, including their disability levels and their homes' interior design. Such a process requires several home visits and iterations of AT interventions by the OTs (Cumming, 1999). In addition, OTs need to visually communicate the home modification plans to PwIDs. Current OT strategies for dealing with these issues are limited to providing a demonstration with randomly available ATs through paper printouts and online images of ATs (e.g., through the North Coast Medical or Amazon websites). However, this process can lead to the purchase of an AT that does not fit PwIDs' home environment. On the

contrary, OTs do not have access to the whole range of ATs available from medical-supply companies for demo purposes. Without such demos of the ATs, thereby only having 2D images as resources, it is difficult for PwIDs to imagine or speculate the application of an AT in their own three-dimensional space. The ineffectiveness of the process frequently generates non-compliance with ill-fitting interventions, and this may result in PwIDs abandoning the ATs.

1.2 Problem Significance

ATs help PwIDs to complete tasks and to maintain their functional independence at home. According to the World Health Organization (WHO), over one billion people globally need one or more assistive products, and over two billion people will need at least one assistive product by 2030 (World Health Organization, 2020). Without ATs, PwIDs are often excluded, isolated, and lead to an increase of disease and disability in a person, their family and society (Money, 2009).

Although ATs are crucial to improve people's lives, getting the appropriate ATs is very difficult. Currently, only 10% of people in need have access to ATs due to their high costs and a lack of awareness, availability, and customization (World Health Organization, 2020). Furthermore, a study by Phillips et al. shows that 29.3% of purchased ATs end up unused or abandoned due to a lack of proper fit or insufficient consultation with PwIDs (Betsy, 1999). Involving PwIDs sufficiently in the selection of

ATs by enabling them to observe and interact with ATs is crucial to assess compatibility with the home environment and lower AT abandonment (Gitlin, 1996).

Hence, people have explored and developed AT codesign platforms to empower OTs to 3D model and print ATs themselves to increase customization and ultimately reduce AT abandonment (Branham, 2015). These platforms leverage OTs expertise to easily produce customized ATs for each unique PwIDs with much lower price. However, the platforms require 3D model software and 3D printing machines, both of which cannot be brought to PwIDs' homes during the home visits. This creates a large gap between OTs and PwIDs. OTs would have to bring in 3D models, ask for feedback, go back to the office to modify, and try again. It is, therefore, always crucial to design a platform for OTs to perform any forms of home modification directly at the homes of PwIDs to involve them in the whole process.

1.3 Objective and Specific Aims

The objective of this project is to design and develop a tool for OTs to search, find, and select ATs for homes and to demonstrate home modification plans together with PwIDs. Particularly, for this project, the goal is to use AR technology to superimpose 3D models of ATs onto the home environment to envision the most appropriate scenarios for purchasing and utilizing ATs in PwIDs' homes.

The authors of this project aim to first review existing literature for AT, OT, mixed reality application in healthcare and home modification. Then it uses

semi-structured interviews to engage four OTs to understand their current process and pain points. It also uses a participatory design approach with two OTs to refine design objects and codesign the AR prototype (including AT search user interface design, AT demo interface design in AR, and call-to-actions to purchase AT or print screenshots). The final prototype was designed, developed, and iterated based on the above feedback and input. Finally, we conducted user studies with 10 OTs to evaluate and refine the AR tool to assess its efficiency, usability, and discuss potential future work.

CHAPTER 2. LITERATURE REVIEW

2.1 Assistive Technology and Occupational Therapy

According to The Assistive Technology Act of 2004, an AT device is an item or piece of equipment that is used to increase, maintain, or improve the functional capabilities of PwIDs and is often either acquired commercially off-the-shelf or customized to fit their specific needs (Assistive Technology Act, 2004). The customization is often done by OTs who can assess PwIDs' needs, but these customizations are limited by lack of materials, time and access to training (McDonald, 2016). In fact, according to the Department of Commerce report on Technology Assessment of the U.S. Assistive Technology Industry, "Certified Rehabilitation Techs, Occupational Therapists with design/manufacturing skills" is reported as one of the AT Industry Skills Shortages (Technology Assessment of the U.S. Assistive Technology Industry, 2003). Several researchers have explored and developed user-friendly 3D modeling and printing software to empower OTs to customize any ATs with minimal training (McDonald., 2016; Buehler, 2014; Atwa, 2013)

These platforms require the OTs to be at their office with a computer that has 3D model software and access to 3D printing machines. However, in many cases, the process of finding and purchasing or modifying ATs for PwIDs requires OTs to visit home and work with PwIDs and communicate the use of ATs (Cumming et al., 1999). Without giving PwIDs the opportunity to work with OTs and pick ATs together, PwIDs tend to

abandon the ATs due to their incompatibility with the specific impairments, lifestyle, or home environment (Gitlin et al., 1996). In this project, we focus on designing a platform that can be accessed through phone or tablet so OTs can bring the software to homes of PwIDs to involve them in the process. In particular, we focus on utilizing the latest AR technology by Apple to superimpose ATs onto the home environment so that both OTs and PwIDs can visually observe how the ATs look during home intervention session and assess the ATs' compatibility with the home.

2.2 Digital Technologies in Occupational Therapy Practices

2.2.1 Parametric 3D CAD Modeling

Parametric CAD enables the addition of design semantics to any model, meaning OTs can rapidly alter existing AT models by simply editing the values of parameters such as width and diameter (Camba et al., 2016). Currently, it is difficult to achieve such a level of flexibility and adaptability of a 3D model due to the complexity of parameters and lack of intuitive 3D modeling tools.

Additive manufacturing, widely known as 3DP, is a technology that solves the above issue by depositing material layer-by-layer thereby making the tool less complex than the majority of parametric CAD modeling tools (Manogharan et al., 2014). 3DP has also evolved to print not only stronger and more durable models but also fully-functional mechanism systems, such as a claw reacher that the OTs can customize and print out (Campbell et al., 2007). Research has shown that this rapid prototyping method will take

far less time than conventionally manufacturing method and will be able to produce high level customized parts with the same functionality (Gao et al., 2015).

Although parametric modeling is a very effective way to model ATs, it has limitations and challenges. The modeling process requires a high-performance CPU that OTs may not have access to and, more importantly, cannot be transported to the PwIDs' home environment. Hence, the OTs would need to separate the whole process. First, they would have to visit PwIDs' homes to understand the situation. Next, they would have to go back to their office to develop ATs that fit the situation, which OTs would need to bring to PwIDs' homes to get their inputs. As seen, OTs would have to go back and forth to iterate on the ATs. In an ideal situation, Dixon mentions that OTs should work together with PwID at their home environment to both identify problems and discuss solutions like creating or buying AT together (Dixon, 2019). Although 3D modeling can be used to freely customize ATs freely, there are still gaps from PwIDs' needs and their home environment that the AT will be installed at.

2.2.2 Codesign Applications

Collaboration platforms allow users to interact and modify a parameterized model through an accessible web-based software tool. For example, a plugin called Grasshopper was developed at Loughborough University that can be installed to any personal laptop or tablet to easily develop geometric variations such as dimensions, color, and overall ergonomic shape of a ballpoint pen (Ariadi, 2012). This could potentially expand to other objects for ATs such as grab bars or reachers. Another codesign application, Reprise, was

created to specify, generate, and customize household objects. Reprise allows users to choose adaptations based on the object type and apply them freely through sliders so they can, for instance, adjust tightness for gripping (Chen et al., 2016). Because OTs can now download the software on more portable devices, they can use the software to craft 3D models together with PwIDs at their home environment, thereby promoting a collaboration between OTs and PwIDs and reducing the chance of AT abandonments. However, for both software, the 3D models are on the laptop screen and it is still difficult to visualize how the models will look and fit into the home environment.

2.2.3 Mixed Reality: AR and VR

There has been little research on the application of mixed reality in the occupational therapy field. Lee (2017) designed an AR-based Otago exercise to improve the balance efficacy of elderly women, and Toh (2011) developed an AR game to practice functional movement and improve the quality of rehabilitation. However, they mainly use AR's ability of being interactive to provide a cheaper alternative compared to hiring coaches or purchasing equipment for motivating people within rehabilitation sessions. Because these AR games do not use the environment and can be played anywhere, they fail to use AR's full potential to superimpose objects like ATs on-top of people's home environment.

Meanwhile, VR has been used to test and teach PwIDs on understanding the controls of smart ATs around the house (Qamar, 2015). This does insert ATs in the home environment, but the home environment is a mock template and not the actual environment of the PwIDs' homes. A team at Burnel University has also explored using

VR to explain pre-discharge home visit process with a mock template of a home (Atwa, 2013). Although OTs can use this VR software to explain the ATs and their purposes with better visuals than pictures on Internet thereby increasing the ability of PwIDs to understand how the ATs look and may be used, both OTs and PwIDs cannot be confident that the ATs will be proper fits in PwIDs' actual home environment. Hence, AR that places ATs directly in the context in real-time may be better fit to the OT process than VR that uses virtual environments.

2.3 Augmented Reality for Home Intervention

In showing objects such as furniture, there are several applications aimed to aid with the configuration of kitchens or storage modules (Ikea, 2017; Cubit, 2017). However, most of these applications are web-based and 2D and do not portray the 3D spacing of objects. Leena studies the use of VR to show 3D objects but uses templates of a fake home environment (Ventä-Olkkonen, 2014). For people to visualize the objects in their own home environment, the application should be phone- or tablet-based and use AR instead of VR to show 3D objects on top of an existing environment.

AR blends the digital and physical worlds in such a way that virtual objects are superimposed onto the surrounding environment to create a new real-virtual scenario (Pascal, 2019). Previous research into the use of AR in domestic environments demonstrated high potential for deploying AR systems in homes and several applications have already been explored or developed for improving the experience of living at home. For example, an augmented kitchen with overlaid projections on objects can facilitate an

interesting, safe, and accessible cooking experience, an augmented home window can display information or facilitate personal and family communication (Bonanni, 2005; Ventä-Olkkonen, 2014). Although researchers have explored the use of AR in showing a specific object without having to purchase it, only a team at University of Oulu explored the notion of augmented human memory by attaching contents to multiple items that may potentially be utilized in the everyday home surroundings (Colley et al., 2014). These projects can be applied to instead show and superimpose ATs such as customized utensils in the kitchen or grab bars in the hallway. However, these AR systems are not built for OTs and lack features such as searching, showing, and comparing objects like ATs.

Other studies on AR for homes have examined the process of interior design, allowing users to search and manipulate (e.g., inserting, scaling, rotating, moving and/or removing) 3D virtual furniture through an augmented image of the domestic environment (Perusquía-Hernández, 2014; Siltanen, 2013). Shin (2018) researched the process of collaborating and designing living rooms together with a virtual workspace that scans the home environment, and Siltanen (2013) developed a tool to replace real-life objects with AR objects that users can search to modify the home environment. However, both are developed with outdated AR technology, where one requires QR code and one cannot place on vertical surfaces like a wall. Therefore, there is a potential in incorporating the latest AR technology for OTs to flexibly place ATs on any home environment.

2.4 AR and Assistive Technology

In terms of using AR to show ATs, only Bianco et al. (2016) demonstrated the benefits of an AR home-modification prototype for elderly-fall prevention, and Djajadiningrat et al. (2016) illustrated the challenges of patients in unassisted care at home and how an AR health application facilitates testing blood at home. However, these systems were developed solely to show one type of AT such as grab bars or blood monitors. OTs must be able to search and show various ATs for PwIDs with various disabilities and impairments, and thus, the potential exists for investigating the application of AR in home health and rehabilitation contexts.

In addition, the above projects only place the ATs in AR. They do not provide any interaction. A common cause of AT abandonment is the lack of involvement from PwIDs in the selection process (Petrie, 2018). Ideally, PwIDs should be able to also move ATs around in AR and give inputs to the details such as placement and size. Luo has implemented AR software for post-stroke hand opening rehabilitation by scanning hands and customizing gloves with the users (Luo, 2005). Although his AR technology is outdated and cannot scan complicated surfaces such as bathroom floors or kitchen walls, the user study has shown that AR provided overall improvement in rehabilitation. This proves that not only AR has the potential to involve PwIDs to reduce abandonment, but the visualization of ATs can make OTs confident that they will ultimately increase the quality of life of PwIDs.

AR can also work with complex ATs as well such as EEG, heart rate, EDA monitors that can help clarify the usage to all users including OTs and PwIDs (Salgado,

2018). In fact, recent AR technology has the ability to scan any new environment and show even the intricate details of objects such as internal jugular vein for medical training and CT scans onto a patient's body (Huang, 2018; Watts, 2017). Both are effective AR tools to give context, as looking at 2D flat images are insufficient for people to interpret and understand deeply. On the contrary, this project aims to build an in-depth catalog of ATs, utilize AR's ability to superimpose ATs onto the PwIDs' home environment, and support the whole process of OT's home modification with involvement from PwIDs themselves.

CHAPTER 3. METHODOLOGY

3.1 Design Methodology Overview

We utilized a research-through-design method i.e., an iterative approach to design the AR tool with OTs, including working professionals, professors with past experience, and PhD students from United Cerebral Palsy of Georgia, University of Georgia, and Georgia State University. The two roles involved in this system are the followings:

1. OT: People who have formal clinical training about how to provide AT services
2. PwID: People with disabilities or impairments, and need AT installments in their home to improve their well-beings and assist their daily activities.

We started the process by interviewing OTs and developed a preliminary prototype for the AR accordingly. In addition, we conducted a participatory workshop in which we assessed the preliminary prototype and determined task structures with OTs. From this, we iterated and developed the final fully-functional AR prototype which we then used to conduct user study that includes think-aloud sessions and qualitative interviews around completing given tasks.

3.2 Prototype Tools and Software

3.2.1 AR Software

This study utilized Apple's ARKit 3, Reality Composer, and RealityKit through Swift programming language. ARKit 3 allows developers to create interactive augmented reality experiences such as placing ATs and being able to adjust their sizes and positions, as well as to scan the environment without any marker placement such as QR codes. We also explored other prototyping methods including: (1) using Unity with Vuforia SDK; (2) Adobe Aero and Adobe Photoshop; (3) Unreal Engine. Unity with Vuforia SDK and Unreal Engine are both among the most popular AR development engines, but both require a marker to scan and place objects. According to our preliminary research, OTs mentioned the benefit of placing ATs anywhere without bringing QR code and putting it up on floors or walls. Adobe Aero and Adobe Photoshop do not allow for integration with custom 3D objects, such as ATs, and they do not enable flexible interaction with the objects through custom code.

3.2.2 3D Modeling

To test the AR prototype with actual ATs, we used two methods: (1) buy existing 3D models on Turbosquid, and (2) model our own through AutoCAD. Through our preliminary research, we had built a list of top ATs that OTs suggest to PwIDs in their past experience. Many of the 3D models of the ATs were found on Turbosquid, but few had minor problems such as no texture or no color that were then customized using AutoCAD.

3.2.3 AR Hardware Device

We used iPad Air 3rd generation to implement and run the AR prototype. In order to work with ARKit, we were limited to using Apple devices. We had considered other devices such as the latest iPhone or iPad Pro, but OTs mentioned that the iPhone screen was too small to view the AR with PwIDs and the iPad Pro was too big to carry around to PwIDs' homes. Our iPad Air is running its latest OS version of 13.3.1 to be compatible with ARKit's latest scanning and detection SDK.

3.3 Semi-Structured Interviews

We conducted semi-structured interviews with four OTs in their work environments to understand the process involved in assessing PwIDs' needs, helping them with home modifications, and selecting assistive devices. Specifically, we asked them to verbally explain how they currently assess PwIDs' needs in their homes and the process of searching and suggesting ATs that match the needs. To dive into the details, we followed up by asking common strategies or difficulties that they may have encountered in assisting their PwIDs, which led to conversations around their current solution as well as their ideal solution given that they have all the resources and time.

We also demonstrated an existing AR app to understand their thoughts behind the potential of AR with showing ATs. We showed IKEA place, an iOS app made by IKEA to place 3D models of furniture onto real environments through AR, through our iPad. OTs also tried the app and gave feedback around the application of AR in their process to

solve their difficulties. We concluded by asking an open-ended question of if they would use AR during their home visit session and how AR would match their ideal process.

None of the OTs had ever used AR, and while all OTs had experience working as home care providers, their levels of expertise varied, from expert practitioner and university professor to novice practitioner/graduate student. Each interview took 45 to 75 minutes to complete (with an average of one hour). After completion of each interview, the data was transcribed and organized into spreadsheets. We analyzed and compiled the data into codes using the thematic analysis technique to examine the data closely and to identify common themes that we used to build our preliminary AR tool. We anonymized participants' names (P1–P4) to protect their identities and used the qualitative result to design and develop our preliminary prototype.

3.4 Codesigning the AR Tool with OTs

We conducted a participatory workshop to make a formative assessment on the preliminary prototype and to codesign the tool with two experienced OTs who were part of the semi-structured interviews labeled P1 and P2. The workshop took two hours to complete, and we followed a predetermined procedure to collect data on the tool requirements and features. Prior to the workshop, we developed a codesign toolkit, which included printouts of all interfaces in the prototype with placeholder boxes (Appendix A). The printouts were supplemented with 50 picture cutouts of various ATs recommended by OTs, and the participants were able to place them on to the placeholder boxes and move it around freely based on their judgment. The participants were also able to write

down text in boxes and throughout the printouts to label buttons, categories, and describe their ideal user flow. These templates enabled the OTs to share their opinions on their preferred approach for categorizing, searching, selecting, and demonstrating ATs in the PwIDs' home environments and what other features would be required in relation to the tasks or activities to be performed (Figures 1). We divided the workshop into four sections.

Figure 1 parts A, B, C – Images from a participatory workshop with two OTs. They interacted with the tool and identified methods of categorizing, searching, selecting, and demonstrating ATs with the AR tool.

3.4.1 Categorizing ATs

The goal was to identify which ATs the OTs regularly recommend to PwIDs and how they would prefer to categorize these items for the purpose of searching and finding

them effortlessly later. We asked the OTs to brainstorm and write down popular or common ATs for home care use on individual post-it notes, which we used to discuss the best strategies for categorizing the ATs. We provided various colors of post-it notes to label various levels of hierarchy: for example, a grab bar may apply to PwIDs with past stroke experience but it may also apply to a bigger category of bathroom. The two OTs were encouraged to work together to come up with a comprehensive list of ATs and a guide to categorize them.

3.4.2 Searching for ATs

We provided the OTs with 50 cut-out images of ATs and templates for placing the images and above post-it notes to determine the best strategy for searching effectively for ATs in the AR tool. Each template consisted of a user interface with blank boxes so OTs can place categories or ATs to design their own user flow based on how they imagine navigating through the search portion. When they felt stuck, we encouraged them to discuss how they search now using Amazon or other specialized websites for ATs and brainstorm the pros and cons. We focused on understanding the cons and the ideal user flow - the cut-out images and post-its allowed OTs to rearrange and try various ideas to design their best version of user interface and flow.

3.4.3 Selection ATs

We used the same template to ask the OTs to write the types of information they would require when sorting and selecting ATs for demo purposes. To guide them for

design, we also provided templates with lines to indicate where the information could be: for instance, under grab bars, we provided a few lines and asked them to list information they see on Amazon and that they want to see.

We also provided a template of the item overview page with empty buttons to indicate features that they wanted to see. We asked them to describe the feature and label the button, as well as draw or write what the feature should do next to the buttons. Finally, we ranked the information and features into most important to least important to understand the information hierarchy of the design.

3.4.4 Demonstration ATs Using AR

Using the Wizard of Oz simulation method and our preliminary AR prototype on our iPad that could show a simple grab bar as AR, we asked the OTs to provide us with formative feedback by verbally describing to us how they would like to interact with the tool when assisting PwIDs. They were also given a print-out of the AR screen to directly draw text, buttons, or features that they want the prototype to include. Overall, the codesign workshop enabled us to collect a detailed list of design requirements from the OTs, which informed the development of the next iteration of the AR tool.

3.5 User Study with OTs

We recruited 10 participants who have been practicing in the OT home modification practice ranging from 1 year to 20+ years (Table 1). One participant is currently a professor teaching Occupational Therapy at Georgia State University, and the

other nine are all current OTs who are still working in the home modification and home care field in Atlanta. We recruited by posting on OT association websites and OT Facebook pages, as well as asking previous participants to introduce other local OTs to our study. We conducted all the user studies individually as one-on-one.

Table 1 – List of participants labeled from P1-P10, their current occupation and organization, as well as their number of years in OT practice

Participants	Current Occupation/Organization	Number of years in OT practice
P1	OTR/L (Occupational Therapist Registered/Licensed) / United Cerebral Palsy	24
P2	OTR/L / Gentiva Home Healthcare	12
P3	OTR/L / Individual	27
P4	OTR/L / Guardian Home Health	28
P5	OTR/L / WellStar Atlanta Medical Center	14
P6	Clinic Director / Therapy Works, PC	12
P7	OT Professor / Georgia State University	10
P8	OT PhD Student / Georgia State University	1.5
P9	OTR/L / Atlanta Speech School	20
P10	OTR/L / Atlanta Autism Center	9

For three participants (P1, P8, P9), we conducted the user study face-to-face at their respective workplaces (Figure 2 Part A). Among the three, P1 invited his current

client to try the AR tool together. For the remaining seven participants (P2-P7, P10), due to COVID-19 and social distancing, we had to conduct a remote user study. Remote user study is common in 2D interface design projects such as apps or websites, as the participants can share their screens and think aloud through a video call (Arena, 2016; Atterer, 2006; Mirroson, 2014). However, remote user study for AR is a new method due to the importance of connecting with the real environment simultaneously with the participants, because AR places objects on top of the environment. Here, we shipped our iPad with the preinstalled AR tool as an app to the participants' houses and conducted the user study remotely through video call, so the participants can still experience the AR at their own home environment as well as be able to think aloud while we see the exact interface in real-time through screen share (Figure 2 Part B, C).

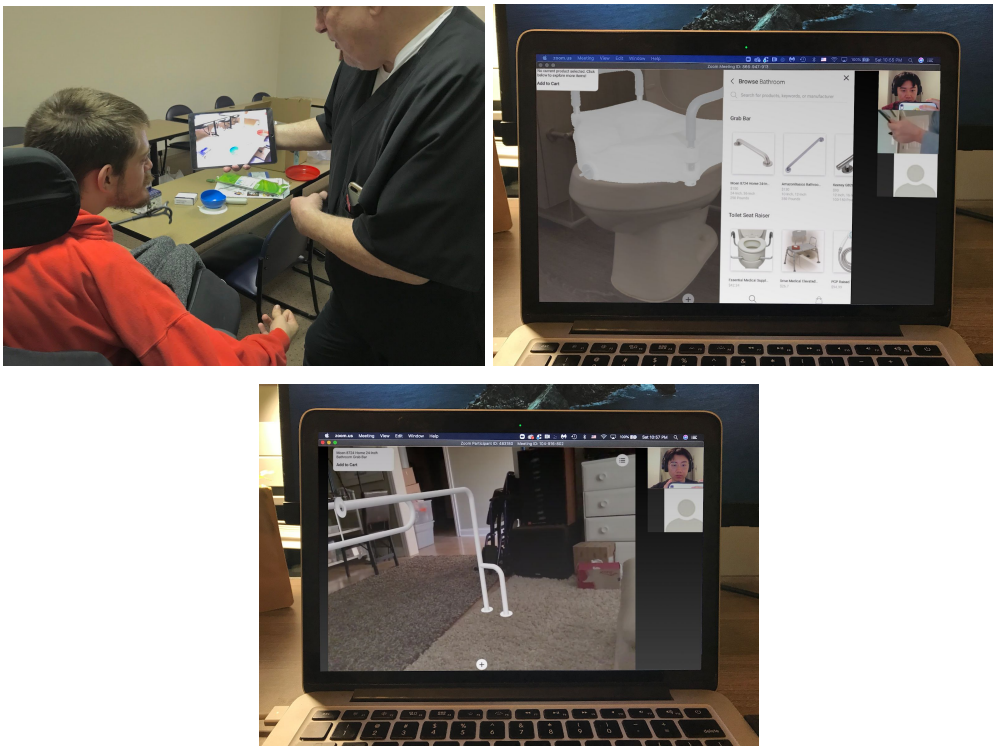


Figure 2 parts A, B, C – Images from user studies from three of the 10 participants. They interacted with the AR tool based on the task given and were interviewed about their overall experience. The first shows a face-to-face user study session, and the other two show remote user study sessions in which the participants were given an iPad with the AR tool.

The overall structure of the user study was kept consistent, which is divided into two sections.

3.5.1 Demo of AR Tool

We briefly described the purpose of the AR tool - that it can show both OTs and PwIDs a 3D model of the ATs on top of the actual environment so they can both visualize the ATs in the context. We then walked through the app's core functions to search, select, and display in AR by simulating a real scenario of OT process: we provide a task to complete by OTs and asked them to suggest a grab bar for their bathroom, look for few grab bars that may be fitting, then try the AR to see the grab bars in the environment. For the remote video call sessions, we set up the call to be able to see both the participants and the iPad screen, so we verbally instructed and guided them through the functions as if we were there. We have considered video call demo from our end and OTs simply watching us demo in my own room, but we wanted the OTs to experience the full AR demo by having the iPad and placing ATs in their own home environment. Hence, as we mentioned, we shipped the iPad and allowed OTs to conduct the demo at their own houses.

3.5.2 Task and Think Aloud

We then asked the participants to restart the AR tool and demonstrate two or more ATs in AR as if they are using the AR tool in the real home modification session with their PwIDs by themselves. We encouraged the participants to think aloud and mention any difficulties or thoughts that they have. If they became stuck in the process, we gave hints to guide them. For example, if they did not know how to place an AR object, we would tell them to try looking for a certain button. We also encourage the participants to imagine a real OT session as if they are working for a specific PwID. That way, they can show two or more ATs and conduct a home modification demo with a purpose that mimics a real session. For the remote video call user studies, as mentioned, we were able to see both the participants and the screens to assess whenever they are stuck. We recorded all sessions to transcribe after and categorize for emerging themes accordingly.

3.5.3 Interview

After the think aloud session, we interviewed the participants for feedback. We divided the interviews into three sections: task complexity, the usability of the interaction, and likability and satisfaction. We first opened up by asking how the AR experience was. We guided the interview to focus on any designs with which they encountered problems when placing a grab bar in AR. The OTs were able to try again to walk through the screens to explain their thought processes with visuals. We also asked about if there were any features that they thought would enhance their current OT process or that they thought were lacking.

We then asked for their opinions about the usability of the app. We asked the overall opinion about the side navigation and if it supported OT's process of searching ATs. If they became stuck, then we asked them to open the AR tool and talk about any designs that were confusing or features that were missing. We also asked about their opinions on the overall flow of scrolling and searching, as well as skimming the AT details to assess if there is a lack of information to help search for specific ATs.

Finally, we asked general questions about the likability and satisfaction of the AR tool by asking about the overall experience. We encouraged the OTs to talk about specific features that they like the most about the AR tool and about how the AR tool will change the ways they provide home modification support to PwIDs. We then ended the user study by asking if they would use the AR tool in the future during their OT sessions. These interview results were transcribed and categorized using an affinity map to follow thematic analysis process and identify common themes. The affinity map was examined iteratively through several stages of linking and reassigning themes and sub-themes. For a detailed description of the thematic analysis process, see Joffe and Yardley (Joffe, 2004). We anonymized participants' names (P1–P10) to protect their identities.

CHAPTER 4. DESIGN DECISIONS & FINDINGS

4.1 Findings from Semi-Structured Interviews

4.1.1 Qualitative Result

The interview findings revealed significant potential for an AR tool prototype for demonstration purposes in home intervention. The interview results revealed that having 3D demos of ATs is the most effective of all strategies used by OTs to introduce ATs to users for home intervention purposes. As P1 noted, “That's the primary way that people can figure out if it's going to work for them or not.” However, currently, the central method for introducing potential ATs to the PwIDs is through online resources, and as P2 described: “I show people pictures of certain things on the internet and say, hey, there's this equipment available to you and this is what it would do. But we don't have the option to see how it functions and then they have to make the choice if they're going to buy it or not.”

Some OTs take demo kits that include common items, such as grabbers, to users’ homes. P4 said, “This show- and-tell allow(s) the client to visually interact and see them in the environment.” However, OTs do not always have access to demo kits, and their limited resources pose a significant challenge to their ability to help users. Both P2 and P4 described how they buy equipment that they frequently recommend and “bring it to a session to demo it and have them try it.” This is not an issue for OTs who work in clinics, as P2 described: “We kept some equipment on hand. In that way, even in (the) outpatient

rehab department, I could show clients what a tub bench looks like. And that way, I could demonstrate." She continued: "I feel like verbally saying you need to install (a) raised toilet. It's, like, hard for people to understand what that looks like or what that is."

The main concern expressed by OTs related to clients' ability to accept or to integrate the AT into their lives. As P3 commented, "If you design a really cool device for someone to use but they don't see any value in it, it's going to be a dust collector." The OTs said that the high cost of ATs supports the need for virtual demos before making purchases. As P3 explained, "If I'm recommending a computer-accessible desk for him that might cost a couple of thousand, if we could put that virtually in their home and show them where it would be and see how so that they can see (it), that's perfect!" We have used the above inputs and concerns to make a user journey map that includes common steps and frustrations face by OTs in the home modification process (Figure 3)

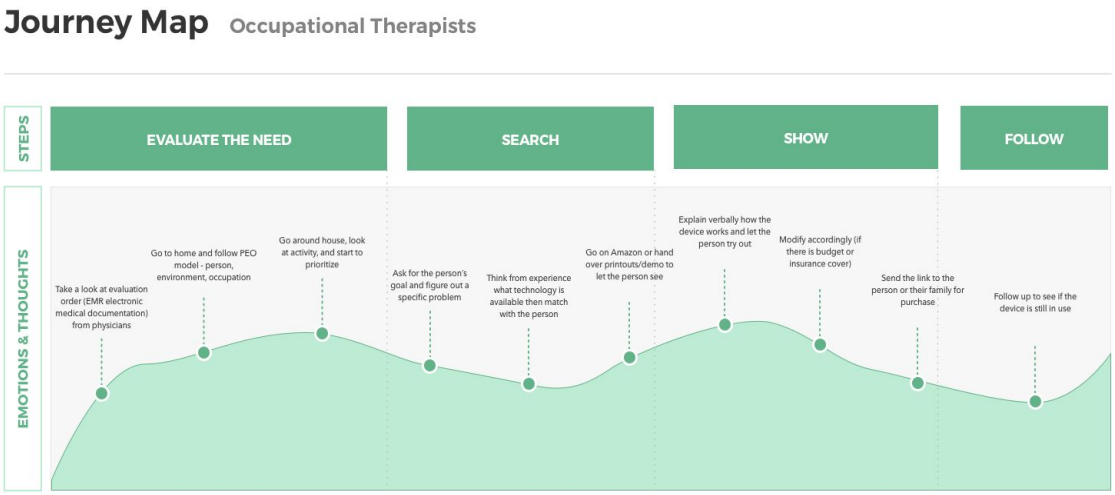


Figure 3 – Journey map that summarizes the common steps of OT home modification process and current frustrations associated with each step.

4.1.2 First Iteration of AR Prototype

Based on the results from the interviews with the OTs, related work in AR, and our personal experience, we created a preliminary AR prototype (Figures 8, 9) using Apple's ARKit3 and the Reality Composer. The ARKit3 comes with presets of AR tools, including Swift codes for environmental scans and object placements. The Reality Composer allows developers to import 3D objects and to create interactive buttons to provide UI and UX flows to the AR prototype. We initially decided to create the prototype using Unity and Vuforia SDK, but the latter requires the use of a printed QR code. After discussing this issue with the OTs, we found that the QR code can limit where they can place ATs and decided to use ARKit3 to place objects directly into any home environments like on a wall or on a toilet. OTs can also freely place multiple ATs in the environment without worrying about how many QR codes they bring to the session. The preliminary prototype development enabled us to go back to the OTs to collect further information on the preliminary invention idea as well as to create further refinements to the prototype through the codesign activity.

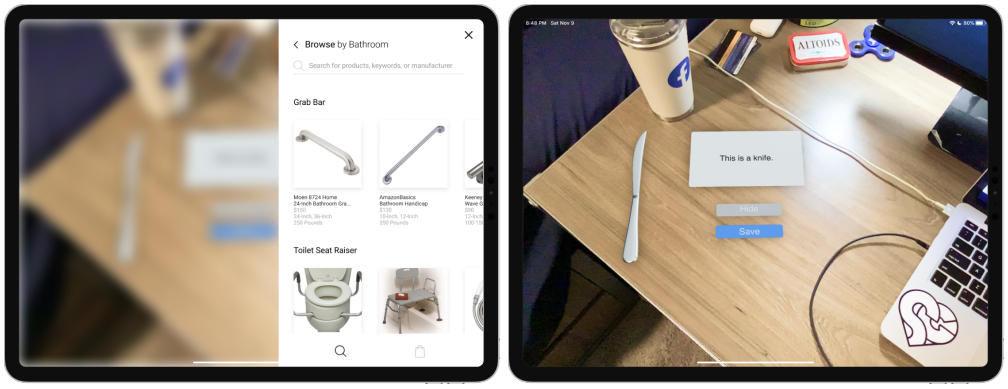


Figure 4 parts A, B – The preliminary augmented reality prototype, developed using feedback from interviews on related work with AT in homes

4.2 Findings from Codesign Session

4.2.1 Qualitative Result

The outcome of the participatory workshop with OTs was transcribed and coded with thematic analysis to identify common themes. The themes provided us with six critical design requirements to include in the further development of the AR prototype:

- Browsing ATs: The OTs' preferred method for categorizing and filtering ATs is by their location in the home (e.g., bathroom, bedroom, and kitchen), followed by categories that relate to activity type (e.g., toileting, bathing, and cooking) and to the type of disability (e.g., people with spinal cord injury, arthritis, or stroke). These strategies should be particularly beneficial to novice OTs, as P1 mentions that "new OTs currently have hard time finding items on Amazon, and these categories can allow them to explore and discover new ones for their clients" and P2 mentions that "even for us who have been doing home care for long time, being able to select location of home and navigate through, it'll make our searching process much more intuitive." However, experienced OTs should be able to search for ATs by using keywords in the search bar (e.g., 3-in-1 bedside commode) or by choosing a manufacturer they trust (e.g. Active Aid 10), based on their familiarity with existing ATs in the market. P1 mentions that "OTs usually suggest the same set of ATs so being able to search the names directly or

even being able to favorite ATs and save a list would make the browsing so much faster."

- AT Information: OTs need instant access to product information, including size (full measurements), weight, and price, as each item necessitates specific assessment by the OT. P1 mentions that for instance, when selecting a grab bar or grabber tool, "knowing its length is critical information to show on the design, but for a toilet seat raiser, the height would be important to show. The design should follow the specific AT but it should definitely show these important product info that we use to make judgement on which to suggest." P2 mentions that "besides these measurements, pricing is also important, because so many times the ATs are not covered by the client's insurance and are paid out of pocket. It would be nice if the pricing and measurements appear during the search, so we can just narrow down our choices and only show ones that match the client's needs." Other factors include the materials and installment plans that make it possible to assess the feasibility of installing an AT in PwIDs' homes.
- Demonstrating ATs to users: OTs should be able to display AT interventions (together with associated information such as measurements and price) on tablet screens and have the ability to hide information for an explicit demonstration so the OTs and PwIDs can focus on seeing the ATs in AR. Both OTs drew boxes on top left to indicate where the information could go and indicated that they wanted a quick way to add the AT to cart to keep track of what ATs the PwIDs want to purchase.

- Manipulating ATs: OTs need to be able to manipulate and interact with an item in three ways: 1) move it on the iPad to adjust its position, 2) lock it into the real environment, and 3) replace it with similar items to showcase/compare products. For instance, if they were to demonstrate a bathroom-seat raiser, they would want to show two examples in succession to compare how they would fit into the space. Also, for smaller hand-held items (e.g., a rocker knife), they would like to place them side by side to note similarities or dissimilarities between them.
- Inventory of ATs: A shopping cart type feature should show the total price of the recommended ATs. The OTs should also be able to add items manually or compare items on a list. The OTs also asked for a list of favorite ATs on which to record items for future quick access.
- Other functionalities: The OTs should be able to take a screenshot of an AT's placement in the home environment, and also email or print images of selected ATs for PwIds. They also wanted a video tutorial that shows first-time OT users how the device is to be used.

4.2.2 Second Iteration of the AR Tool

The above feedback enabled us to improve the navigation, the AR experience, and the overall features to iterate and finish our final prototype. Because the OTs wanted specific measurement and pricing for each ATs, instead of manually adding ATs to our list, we built a Python Web Scraper to scrape ATs from Amazon to our database and cleaned the data to fit the style of name, measurement, pricing, and pictures. We then

used the suggestions from OTs to categorize and tag the ATs based on their intended location, activity type, as well as the type of disability and impairments they support, which we used to design on Figma (Figure 5).

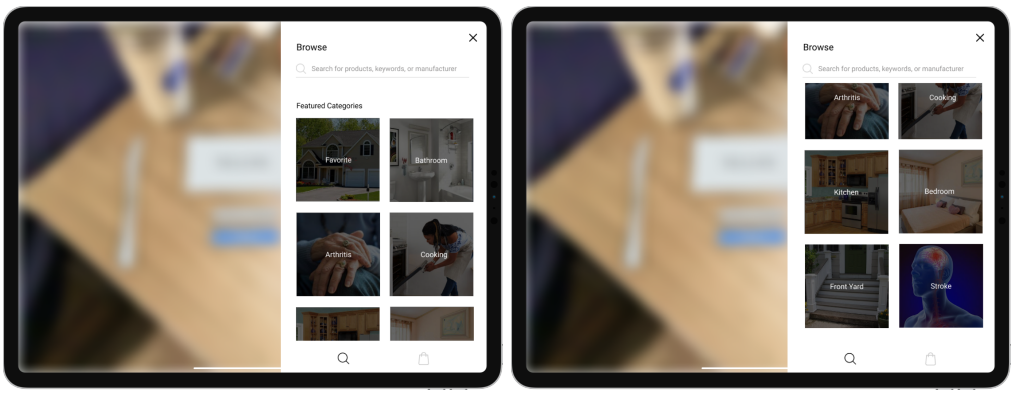


Figure 5 parts A, B – The UI for browsing categories of ATs based on location, activity type, and impairment type.

The AR app was then developed to call and query from the database to fill in the browse and search section. We also iterated the user interface to fit the product information on the browse section by rearranging the information to group relevant information and make the browsing experience more intuitive. We looked at Amazon, eBay, and IKEA for inspiration on the browsing UI and built the layout on Figma and Swift (Figure 6).

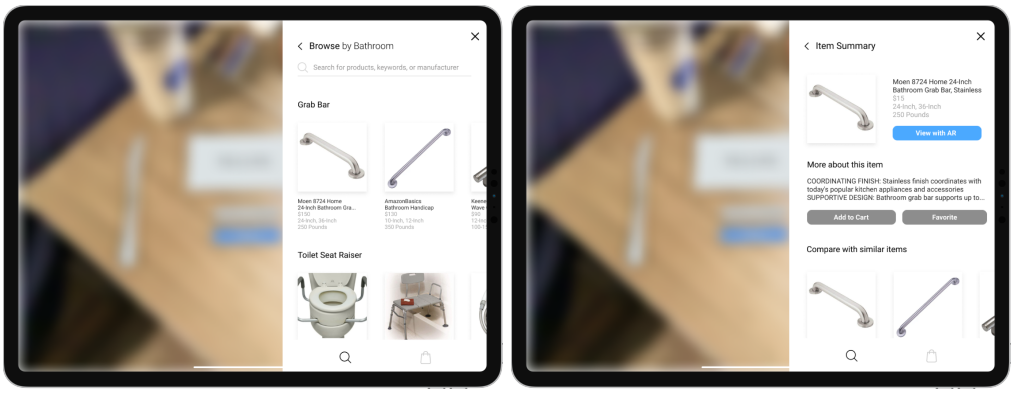


Figure 6 parts A, B – The UI for scrolling through ATs within a category and for reading the summary of the AT that includes its price, measurements, manufacturer, and other similar items.

In addition, for each category, we purchased and cleaned 3D models of two or more ATs. We used Turbosquid to purchase the 3D models because doing so provided the highest definition of 3D models that can be placed in AR and be compatible with ARKit. Below is a list of all ATs that were available on the AR tool (Table 2).

Table 2 – List of ATs with their names, types, and images that were available on the AR tool. The ATs had 3D models that were purchased on Turbosquid.

Name	Type	Image
Toilet Seat Riser	Home AT	

Table 2 continued		
Grab Bar 1	Home AT	
Grab Bar 2	Home AT	
Grab Bar 3	Home AT	
Walking Aid 1	Personal AT	

Table 2 continued		
Walking Aid 2	Personal AT	
Reacher	Personal AT	

Regarding the AR experience, we added the ability for OTs to hold to move ATs around in the environment after placement. We used ARCoaching OverlayView under ARKit SDK to constantly identify the surface so the ATs are still placed on top of the environment when they are being moved instead of floating in the space. We then used ARRayCastQuery to place the ATs when the OTs decide to let go of the hold, so the ATs are locked to their new place that OTs want to put in. This code was also reused to enable OTs to rotate the ATs by pinching them using two fingers. We also considered resizing, but we were using the exact size queried from Amazon so in order to show the exact size and fit of the ATs, we decided not to pursue the ability to change ATs' sizes. We also

developed a card function on top left to indicate what ATs are being placed using SwiftUI that is compatible with ARKit. We then linked the browsing code and the AR experience in XCode to create our fully-functional AR tool as seen below (Figure 7).

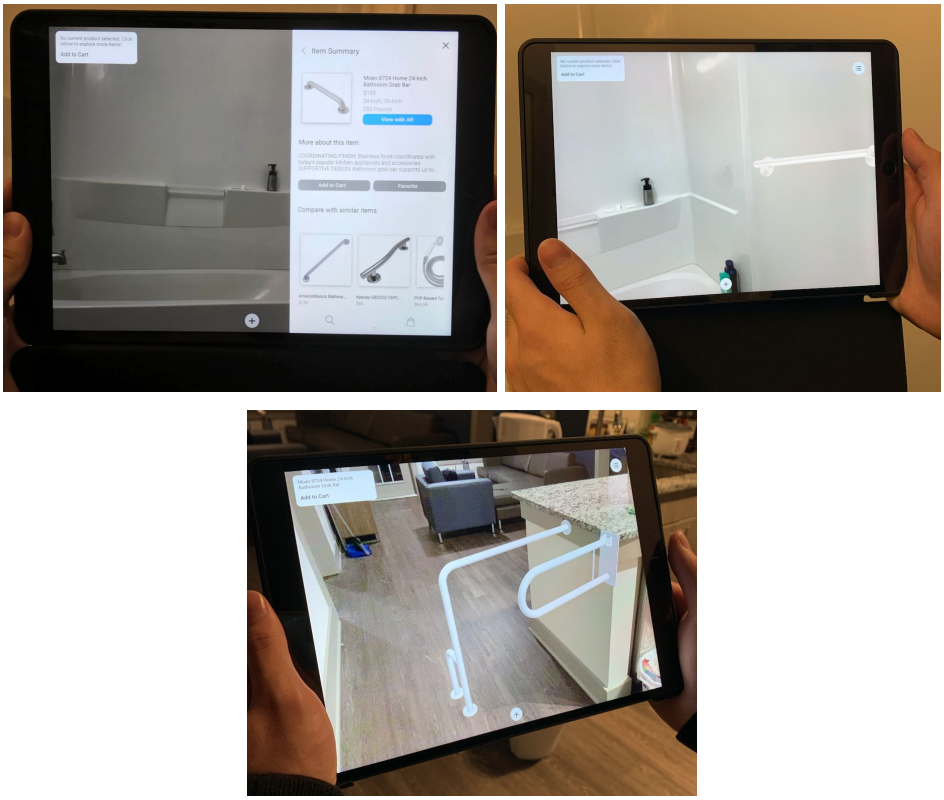


Figure 7 parts A, B, C – The second version of the home-modification AR tool, developed using feedback from OTs during the first participatory workshop.

4.3 Findings from User Study Sessions

The 10 user study sessions with OTs was analyzed into four themes and future potential iterations. A number of sub-themes were identified within the themes, and these are presented as an affinity map in Figure 8.

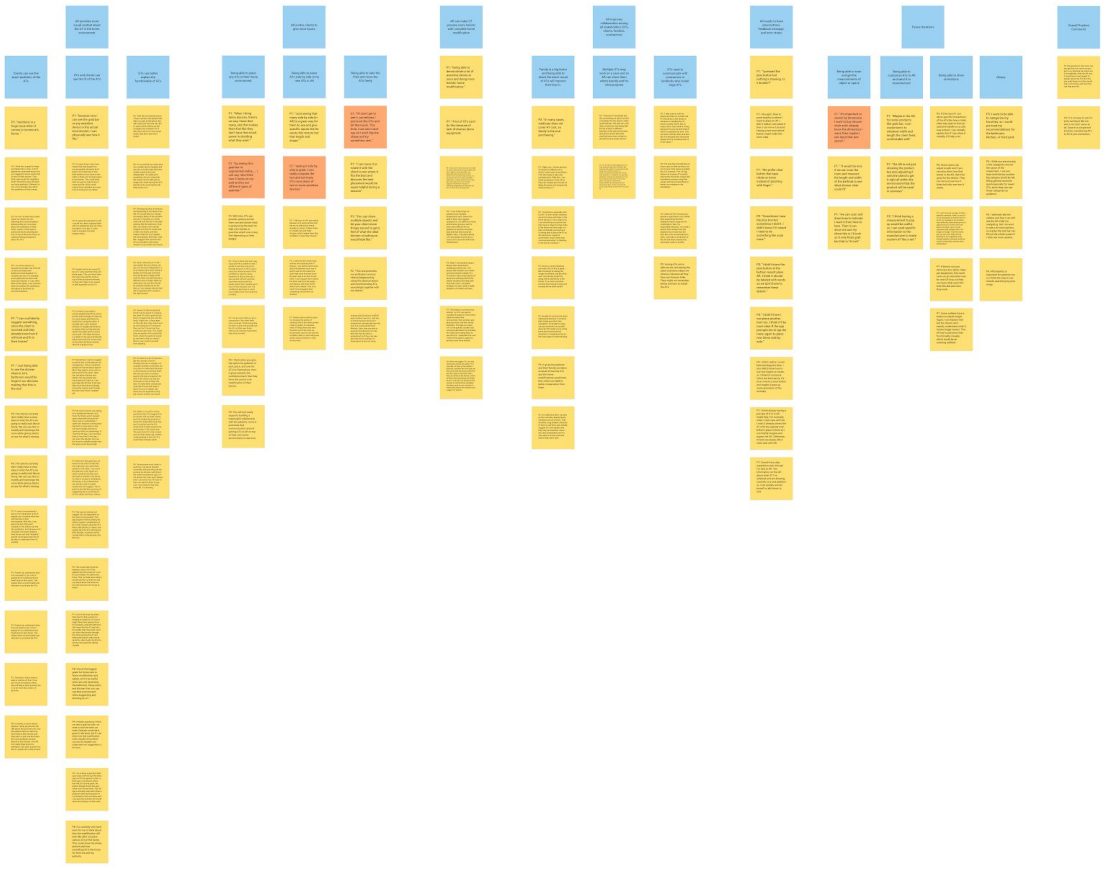


Figure 8 – Thematic affinity map of themes and sub-themes from user study session

4.3.1 AR Provides More Visual Context About the AT in the Home Environment

4.3.1.1 OTs, PwIDs and their caregivers can see the fit of the ATs

In general, most participants were satisfied about the ability to "see what the AT looks like," as P6 summarized. Most participants mentioned that the problem with the current OT process with home modification is that the PwIDs do not visually understand how the AT may fit in their home environment:

> The clients currently don't really have a clear idea of what the ATs are going to really look like at home. We can use this to modify and rearrange the room while giving clients an eye for what's coming. [P5]

> It's currently very hard even for me to think about how the modification will look like after we place various ATs in the home. This could show the whole picture and how everything fit in the home for both me and my patients. [P8]

This is a problem because PwIDs and their family members have false understanding of the ATs' sizes. "I've had a case where I recommended chair lift for stairs, but the client thought it'd take up too much space and block his family from using the stairs. It actually won't and I showed pictures on Google and Amazon to explain that, but the pictures weren't his stairs and he wasn't convinced," as P3 mentioned, "This helps me point my tablet to the stair and directly place items with the correct size, so the client will know exactly what he is going to buy." P3 also gave two other examples where the PwIDs and their family members did not understand the size:

> My client's family was asking for a residential elevator, but I knew that there wasn't enough space especially because the client was on a wheelchair. I spent four sessions coming back and forth to draw dots on the wall and brought pictures to convince them my reasoning. If I had this AR app, I can convince them in less than 5 minutes. I can show the

elevator and use the visual to verbally explain how the space is not big enough. [P3]

Sometimes I need to suggest an entire door in the bedroom for emergencies. This is crucial but people are worried about spaces like if they need to move sofa or bed around to fit a door. Here, you can place the door and clients can see exactly how much space it'll take up. I can also keep the 3D door in AR and help move the bed accordingly during the session even though the door hasn't been installed yet. [P3]

P3 mentioned that the benefit of this tool is to "show them the exact size and the look on top of their actual environment, so they don't have to be scared or take a gamble on the ATs." In fact, understanding the size is crucial as P2 mentioned that she encountered many cases where "I hear from clients that they bought the recommended tub bench but it doesn't fit in their tub or that their bathtub is too close to the toilet so there isn't enough space for the bench. This could show both me and my clients how it looks and fits, which could reduce these mistakes and save a lot of money for my clients." P6 also agreed that "This would help minimize expense, since a lot of the patients buy the wrong AT or an AT but it doesn't fit well at the home. This can help show what it would look like, so both me and my clients know that what we buy will work and will not go to waste."

Besides showing the fit of the AT based on the environment, the AR tool can also provide visual context based on the PwIDs. For instance, P2 mentioned that “If I place the tub bench in AR, I can let my client try going there with his wheelchair and see if the tub bench is too big. It’s very hard to visualize this with images online." P5 and P8 described that this is important because the ATs need to fit the PwID’s conditions:

> The way we choose and suggest ATs are dependent on the client’s functionality. This app supports that by asking the clients maybe in wheelchairs to be in that context, place the ATs there, take photos or videos, and explain how the ATs will improve their lifestyle. A picture cannot include them in the process, but this can. [P5]

> When we suggest ATs, we also holistically assess the patient. For example, we look at the patient’s physical condition like how high can they reach and the environment like are they using a tub bench when they are sitting in the shower, which all affect the positioning and shape of ATs. This puts ATs directly in the context in real time that considers the above, and we can continue to holistically assess the situation and suggest AT options. [P8]

Furthermore, this AR tool can also place the ATs on the environment and allow PwIDs and their family members to be in the frame to screenshot and visualize where the ATs should be. As P4 explained that the former is important

because “Many ATs like grab bars are based on the client’s body like how high they can reach while seated on the toilet. I can move the grab bar in AR, figure out where would be the best spot and mark it exactly in the home.” The PwIDs and their family members can also be in the frame to figure out how much space there is after the AT is installed. P7 mentioned that “A lot of the time, the client feels bad for their partner for needing to install an AT since it might block their partner from, for example, using the bathroom with ease. But the AT may be a lot smaller than they think, and I can show that exactly through the AR by putting the AT and letting the partner walk around while the client holds the iPad to see the new potential setting visually.” P4 also gave an example that “Both my client and I can use the AR and let a family member lie on the bed, so I can explain why the bed rail is important with visuals in the right context.”

Overall, P6 said that “clients are very very visual” and both P1 and P8 commend the AR tool that “because now I can see the grab bar or any assistive device in the actual environment, I can physically see how it fits” and “One of the biggest goals for home care is home modification and safety, so it’s so useful when you are assessing the bathroom, living room, and kitchen that you can use that whole context with the environment and the people when suggesting and showing an AT." P10 concluded that “one of the biggest benefits of having this AR tool would be to be on the same page as the clients since we are all seeing the same item in that specific context real-time." P10 also mentioned that “this can

definitely improve the buy-ins and confidence from the clients from just showing pictures on Amazon."

4.3.1.2 PwIDs can see the exact aesthetics of the ATs

P3 mentioned that "Aesthetic is a huge issue when it comes to someone's home." P7 also mentioned that many PwIDs "care about keeping their homes not look disabled," to which P3 and P6 gave examples:

> I think this is great for large purchases like a ramp. A lot of people are concerned about how our suggested ramps would look in front of their houses. They think what would the neighbors think? Would the ramp diminish my home aesthetic? Believe it or not, a lot of people care about the aesthetics of their homes. [P3]

> Some people never listen to anything I say about bedside commode, because they see the pictures on Amazon and think it will make the bedroom ugly. It's not always the case, and I always wish I can show how it'll look on their own bed for them to see. [P6]

In fact, "currently, to show various options, I bring up pictures and talk about the pros and cons," P8 explained and brought a pain point that "the patients have no idea how that looks in their homes, but they want to pick the one that looks aesthetic and that blends in their homes." P7 also agreed that "a lot of people do not understand how they'll look in their home. This makes them

uncomfortable and reluctant to purchase the ATs." Many participants agreed that "This AR tool really helps show the aesthetics and show exactly how the AT would look in their homes" [P8] and "If we don't have the specific demo, this will help at least envision the AT a lot more than online 2D pictures" [P7].

Understanding the aesthetic of the AT can also make OTs "confidently suggest something, since the client is involved and they already know how it will look and fit in their homes" [P1]. For instance, P1 mentioned that "Just being able to see the shower chair in AJ's bathroom [client's bathroom] would be huge to our decision making that this is the one." P7 also mentioned that "With this, I can place the item there and visualize it, the clients can see the aesthetics."

4.3.1.3 OTs can clearly communicate the functionality of the ATs with PwIDs

One of the current struggles about explaining ATs is that "it is so abstract when I describe items with just pictures on the Internet. Clients never really grasp the purpose even though I try so hard to explain it" [P9]. This is because "A lot of clients have never heard of bedrail" or other ATs and "they get confused how the Amazon image would work for their own bed that has a different size or shape" [P4]. Many participants gave concrete examples of struggles from their past experience:

> "With the tub transfer bench, I show a picture and explain that there is a part of the bench that will extend out from the tub. But so many clients

follow up and complain how it doesn't fit. If they don't see ATs in the actual space, they don't see how it works." [P2]

Some ATs like the bathtub bench may be easier to imagine, but other ATs like a grab bar are hard to imagine the size and the looks. Right now, I place tapes on the wall, but many clients end up not buying the ATs because they just don't know how they would look and work. [P4]

It's hard for a lot of clients to get the concept of the AT through pictures on Google. For example, bedside commodes are very hard to understand because it relies heavily on the bed itself - the way you need to position against the bed and against the wall. [P5]

And many agreed that the AR tool can help "explain with visuals like here's where the grab bar would go and here's why you need it here to, say, protect yourself from slipping" [P4]. In fact, many participants picked up the AR tool and explained how it would change their current OT process:

It's a powerful tool when they can visually see the tangible and see how it would make the home a better place to be more independent. It's really hard sometimes for me to describe the impact of ATs with just an image and I think having the ATs placed on the environment will help clarify a lot. [P2]

> If the clients can see the commode on top of their own bed, it'll make them understand what the ATs are and make it easier for me to explain why those ATs are important using the context of their own home. [P5]

> But so many clients just don't grasp the purpose of some ATs, especially since they can't visualize how the ATs would work in their actual home environment. This solves that. This puts the ATs in the context and can help clients get a better understanding of how the ATs would help increase safety. [P6]

In conclusion, P4 mentioned that "With this, I feel like I suggest and convince the ATs much better with actual visuals on top of their own home" and P5 mentioned that it can "Create a better understanding for the client." P9 summarized that "AR would make OTs explain functionality of items much much better since the items are literally there."

4.3.2 AR Invites PwIDs to Give More Inputs

4.3.2.1 Being able to place any ATs in their home environment

Overall, most participants mentioned the importance of inviting PwIDs into the process, because the OTs "are more likely to get a cooperation if the client feels more involved" [P6]. However, several participants also talked about their past experiences and that it is hard to involve the clients with selection of ATs:

> When I bring demo devices, there's no way I have that many, and that makes them feel like they don't have that much power in deciding what they want. [P1]

> I have a client who had a leg injury and he is unable to walk. I would sit with him and scroll through Amazon to find a good cane, but I knew he wasn't that confident in what he chose because it's all just pictures. [P6]

> The patient I was working with needed a grab bar in his bathroom to prevent him from slipping, and so, I showed him a couple of options on Amazon. He just told me he can't really tell, and in the end I just picked one for him. I think it's difficult for the patients to be motivated to pick items since they feel like they can't see the choices anyways. [P9]

With AR's ability to show ATs in the real space, P8 mentioned that "when you give the option for patients to pick, place, and see the ATs for themselves, then it gives patients the confidence back that they have the control over modification of their homes." P2 and P10 also emphasized the importance of visuals as the tool can "let them see and decide what is going to be the best for their own homes" and "make the clients feel like they are the ones choosing the ATs for their own homes." P8 concluded that "This AR tool really supports building a meaningful relationship with the patients, since it promotes that communication around putting ATs in AR on top of their own home environment in real time." In fact, the PwID who was with P1 during the user study session voiced that

"by seeing this grab bar in AR, I can say I don't like how it looks on my wall and try out different types of grab bars."

4.3.2.2 Being able to show multiple ATs to PwIDs simultaneously

Several participants also commended the AR tool specifically on its ability to "place and see many ATs side by side," as P1 mentioned, because it enables the PwIDs "to see and give specific inputs like he wants this texture but that length and shape." P7 also mentioned that "Side by side would be great for showing the option of materials like if the client prefers metal or plastic or stainless steel. It'll help them pick their favorites out of the ones we recommend, and we can both be confident about it since they saw all the options directly in their environment." P10 mentioned that OT's current method of showing and "seeing pictures side by side don't mean much, since they aren't placed in the patient's homes and they can't exactly understand the difference," and P9 mentioned that "it's unreasonable for us to purchase multiple versions of all possible ATs in the world, even though that would be the ideal scenario. I feel like this AR app is a great alternative to that since it places the items directly on the wall as if they are there."

Other participants found the ability to switch among multiple ATs to show to be the most useful feature from the AR tool to be able to involve PwIDs more into the overall process:

> I like how in AR I can switch between ATs using Similar Item tab so my clients can check wooden or metal. It allows them to visually see and make choices, which makes them feel confident in what they choose. [P3]

> I really like the similar item section and replacing the AT feature. I can easily switch back and forth between seat riser A and B, and the AR makes the client feel more involved since the seat riser is on their actual toilet. I can imagine them taking the iPad, look from all angles, and discuss with their family which one is better. This is so much more engaging than comparing two pictures on Amazon. [P4]

> I try to bring a physical toilet seat raiser with me, but the demo may not fit the patient's toilet. In that case, I say there's others that will, but at that point, the patient already thinks the seat raiser won't fit and work. This AR app is actually even better than a physical toilet seat because I'm not limited to that one demo and I can pick ones that will fit and show them directly on their toilet, which gives them more than one option. [P8]

Overall, as P10 mentioned, "when I tried this app, I can really see myself interacting more with the clients by saying hey here are my suggestions why don't you come see them so we can discuss which one is better." P9 also mentioned that "both the ability to place items side by side and the ability to replace items with similar items are great ways for patients to feel more involved."

4.3.2.3 Being able to interact with the ATs freely

The PwID that was with P1 also tried the AR tool and said that "if I don't get to see it, sometimes I just trust the OTs and let them pick. This time, I can see it and say oh I don't like the shape and try something new." In fact, without this ability, "Some people are not eager to change and say they've lived 80 years without new ATs. And this is mainly because they don't understand conceptually how the new ATs would benefit their lifestyle" [P4]. Hence, because our AR tool is on a portable iPad, PwIDs " are able to see even the abstract ATs like bed rails that are hard to understand, and they can take the iPad and try seeing ATs themselves to find out more" [P4] and "You can show multiple objects and let your client move things around to get a feel of what the ideal kitchen or bathroom would look like" [P1]. P2 and P9 concluded that "This tool promotes our profession and our clinical judgment by using the physical space and recommending ATs accordingly together with our clients," and "what I love about this app is that it's an app on a tablet that I can pass it to my clients and let them see the bedside commodes or walkers from different angles. It makes them feel like it's their choice, because they can see it in their room up close or from far away."

4.3.3 AR Can Make OT Process More Comprehensive

Several OTs emphasized that OTs "need to consider all aspects of the client, which includes their environment, their emotion and physical state, and their family members" [P7]. This typically means that OTs need to be "able to demonstrate a lot of

assistive devices at once and do more holistic home modification" [P1]. However, P1, P2, and P9 agreed that this is very difficult to do currently:

> A lot of OTs can't do this because of lack of diverse demo equipment. [P1]

> I have a lot of demo devices for smaller ATs like a dressing stick, long-handled shoe horn, I keep in my car and then I can physically demonstrate them at their homes. But a lot of the larger devices, it is not practical for me to carry around like toilet seats. I've done a little bit, but it also gets very expensive for me. [P2]

> It's difficult to have all the demo devices, and it's even more difficult for my patients to see how all would look and how they would be helpful. [P2]

> Showing a picture isn't holistic because it doesn't incorporate the environment nor the people. Bringing a demo is holistic, but it is unrealistic for us to purchase all the demos in the world, not just one per equipment but multiple. That's just not possible. [P9]

In fact, "A lot of the times my patients have multiple impairments and I need to be able to show and suggest multiple ATs," P2 stated, "Here, I can place all the ATs and explain one by one or zoom out to show the full home modification." Several participants

gave examples how the tool "maintains OTs job to stay holistic or even make it more visual and more effective" [P10]:

> When I recommend ramps, I always also recommend overhang to block rain. OTs assess the situation as a whole and recommend multiple ATs - it's hard to show stock photos of ramp and overhang and let the clients visualize how they both may look. Here, I can place multiple ATs and I think it really supports our holistic process. [P3]

> This helps our process stay holistic. As OTs, we need to consider all aspects of the client, which includes their environment, their emotion and physical state, and their family members. This app can place ATs in the specific context and communicate better by including the client and inviting them to see the ATs. I really like that, and I think it'll be able to make our process even more holistic. [P7]

4.3.4 AR Improves Collaboration Among All Stakeholders

4.3.4.1 AR can share the same visuals to all family members to improve buy-ins

P2 pointed out that "in many cases, Medicare does not cover AT cost, so family is the one purchasing," and P9 mentioned that "purchasing items and doing home modification needs to include family members who also live there, since the items may affect their daily lives too." Therefore, P5 mentions that "Usually it's not just the client making the decision. It involves their family and all of their caretakers."

P2 mentioned that currently, many OTs "have a printout of a bunch of different ATs, which I write notes on and leave it for the family to refer [to] and purchase later.. The benefit of this AR tool is that OTs are now "able to show not just a picture, but actually show the 3D model on top of the home environment allows everyone to visualize and be on the same page of understanding" [P5]. Several participants gave concrete examples:

> Sometimes, especially with COVID-19, their family members cannot be there with them in the home during OT visit. Right now, I can send Amazon pictures but they have no idea how that looks in the home and they might not feel comfortable purchasing it. So being able to place the AT as AR and send a couple of screenshots would really help communicate what I'm thinking to the family members. [P2]

> It's really nice that I can also do this remotely. Maybe family members are out of town. That would be a big problem, because I'd have to call them and verbally suggest ATs and explain why they may be important. Here, I can send screenshots and it's very easy to involve everyone even if they aren't here. [P6]

P6 summarized that the AR tool "gives the patients and their family members a visual of how the ATs and the home modifications would look like, which can lead to better cooperation from them" and P5 also mentioned that "To be able to show not just a picture, but actually show the 3D model on top of the

home environment allows everyone to visualize and be on the same page of understanding."

4.3.4.2 AR improves collaboration between OTs and OT assistants

P10 mentioned that "many OTs have OT assistants that focus on the follow-ups of home care. They help to work with the clients to make sure they will understand and use whatever modifications we suggest, while we OTs focus on assessing the situation and providing initial suggestions." Currently, OTs "usually call my assistant on the phone, list what items the client needs to have and verbally explain where they should be installed and why" [P10]. However, "sometimes there's a miscommunication between the OTs and their assistant. For instance, OTs say there should be two grab bars in the bathroom, but the assistant places them in the wrong place" [P5]. Several participants mentioned that AR can help reduce any miscommunication:

> I have an OT assistant and she was asking me advice to find a tub bench for her client's rather small bathtub. She sent me a few ideas as pictures, but being able for her to drop in different benches in the real environment and show me how they look would give me more context to provide more accurate advice. [P2]

> This app can improve the communication by storing the AR and sharing that data, so OTs can share the exact visual setting of where the ATs should be. [P5]

> With this app, I can use visuals to tell my assistants what exactly I'm suggesting including what model and where they should be placed, and use the visuals to explain their purposes. [P10]

4.3.4.3 AR helps clarify the installation process of ATs for the installers

"A lot of times, the ATs arrive after the OTs' limited days of home care," P5 stated, "And they or other people set up the ATs without us being there." P5 also mentioned that "Having ATs arrive after we are not seeing the client anymore makes me nervous, because all they have are Amazon links. They might not remember where and how to install the ATs." In fact, P9 stated that "If you install a grab bar or any assistive devices in wrong places, it could lead to potential safety problems. For example, a grab bar needs to be at a certain height so it actually supports the weight of the clients or a bedside commode needs to be installed correctly on a toilet so it doesn't wobble later."

However, currently showing where the ATs should be installed is a difficult process:

> I take a photo with my phone and draw on it where the AT should be so the family or whoever is installing the AT knows exactly where. But so many times, they install it wrong because it's just my brief sketch which is typically just dots. [P2]

> Under the Fair Housing Act, people in apartments can modify their apartments but their landlords need to approve the modification. Now, it's

> impossible, because I can send a picture from Amazon but the landlord won't know how the item fits in the actual bathroom. [P3]

Using this app, OTs "take a screenshot of the AR and share exactly how and where I plan to modify" [P3]. P2 agreed and states that "This can show exactly where and how the ATs like grab bars should be placed since it visualizes the AT in the space." Although currently OTs "don't know if the clients installed the ATs correctly," P5 stated that the app "allows me to place ATs exactly where they should be, explain the installation process using that visual, and send screenshots so there's no mistakes in the installation."

4.3.5 Limitations and Future Iterations of the AR Tool

4.3.5.1 The current tool does not directly show the functionality of ATs

Several participants mentioned that the ATs in AR are not interactive enough and only provide the visuals. P7 mentions that "for each complex AT like a bedside commode, I hope there's a way for me to manipulate and demo the ATs in AR." P3 points out that "I can verbally explain with the AR but if I can show it [the functionality] visually, it'll help even more," to which P10 also mentioned that "3D model can show size and fit, but ultimately it doesn't really show how the item works." Some examples included:

> It'd be nice if I can demo specific interactions of the ATs like how a toilet chair may open or how an assistive handle on a sofa may extend. [P3]

> Some walkers have a button to adjust height. Again, I can explain that but the clients don't exactly understand what 5 inches longer means. This AR tool won't be able to show that functionality visually, since it just shows the still 3D model. [P7]

Ideally, "the clients can actually touch or try the items like be able to try the functionality themselves," as P9 mentioned but also suggests an intermediate step to implement a feature that "play[s] a video of someone else using it so the clients can see how it may be used." P7 also states a similar idea to have "demo video per equipment" and that it can also potentially "serve as an education tool for new OTs too, so they can learn what each ATs look like and also how they work." Overall, the current tool did not show functionality of ATs directly and OTs would still need to rely on their verbal communication to describe a product's functionalities to PwIDs.

4.3.5.2 The current tool does not provide measurements of dimensions

Few participants mentioned that they want the AR to also provide measurements of dimensions such as toilet seat height or door length. For instance, P1 mentioned that currently the tool does not allow OTs to "scan the room and measure the length and width of the bathtub to see what shower chair could fit." The PwID that was with P1 also brought up that "If I want to buy a shower chair and if I already know the dimension I

want [from scanning and obtaining measurements], then maybe I can input that [information to] search."

Currently, OTs “have to measure the door width or other details in a home,” P10 mentioned, “and it’s a very slow process to measure everything, take notes, then finally use the information to search a fitting item." P1 described that ideally OTs would be able to “scan and draw lines to indicate I want it from here to here. Then it can show me and my client this is 16 inches so it only finds a grab bar that is 16 inches.” A feature to support scanning the room and “have a measurement to pop up” [P2] mentioned to be potentially beneficial by several OTs.

4.3.5.3 The current tool does not support customization of ATs

Few participants hoped that there is a feature to customize ATs in AR. For instance, P9 mentioned that the current tool only shows “assistive devices that are available on Amazon and it’s a fixed size, but actually sometimes [OTs] do DIYs to adjust size or shape to fit the client or the home.” These DIY customizations are crucial, as “many times, the devices we recommend get abandoned because they don’t perfectly fit in the home or the needs” [P4] and can lead to “infinite possibilities of assistive devices I can recommend and not just limiting to off-the-shelf products” [P10]. Customizations can include “width and length” of ATs like grab bars [P1] or “add new parts like a joystick to move the wheelchair” [P9]. To emphasize the importance of considering DIY ATs as part of the AR tool, P1 stated: “it is not just showing the product

but also adjusting it with the client to get it right all within the environment that the product will be used in anyway."

4.3.5.4 AR needs to have clear buttons, feedback message, and error state

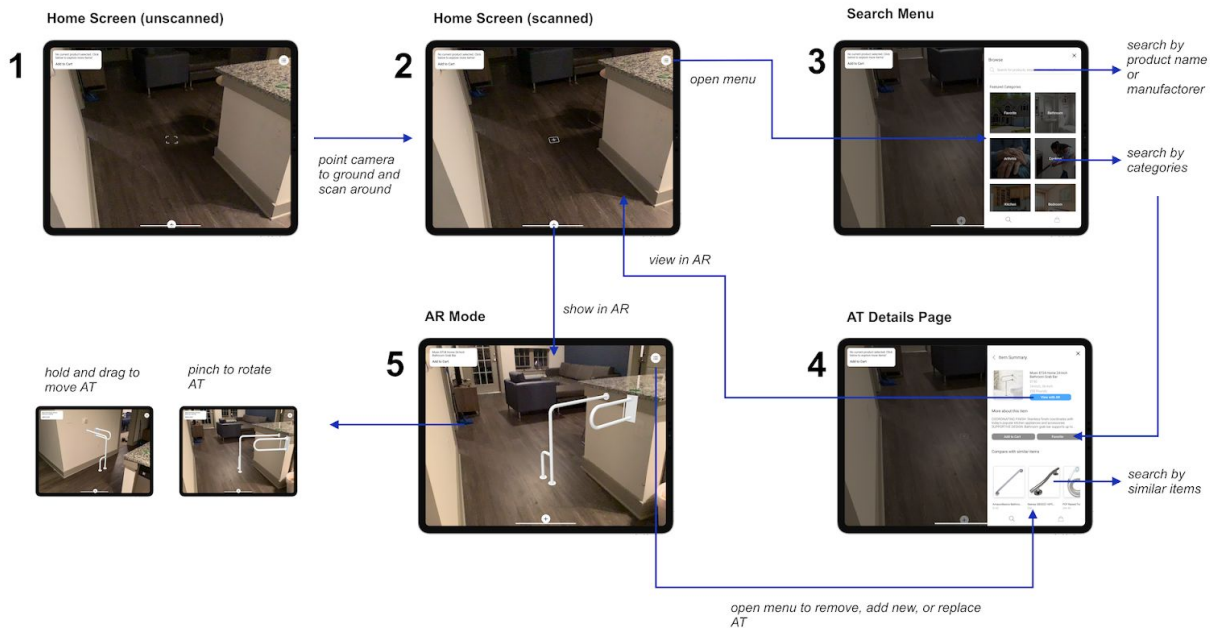


Figure 9 – Storyboard of AR tool broken down to search, select, and show

All participants had no trouble using the first four steps of searching and selecting ATs, but participants struggled with the fifth step of showing ATs and interacting with them in the AR (Figure 9). Several participants stated that they prefer to use buttons than gestures when interacting with specific AR features. For example, P4 stated that "I didn't realize I could hold and drag the item" or struggled to notice that they can interact with the ATs in AR by rotating or replacing with new ones. P1 mentioned that he prefers "a clear button that says rotate or move instead of pinching with finger," and P10 also

brought up that “many OTs are new to tablets, so you can’t rely too much on these common gestures.” Both have helped to draw examples (Figure 10). Without such clear buttons, P7 mentioned that OTs may think they have to “point exactly to where [they] need to place an AT” and not “realize [they] can place it then [they] can move it around.”

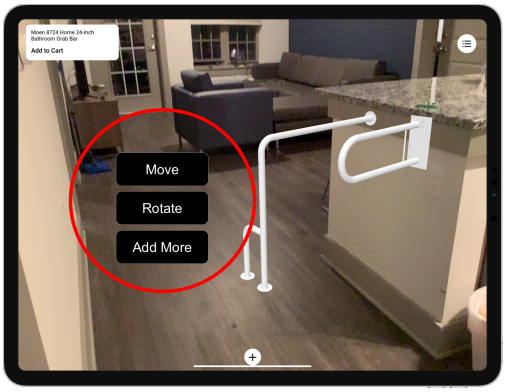


Figure 10 – Button suggestions for future UI iterations

Furthermore, many participants struggled during the scan process. For example, P1 mentioned that he “pressed the plus button but nothing’s showing,” while P2 mentioned “Sometimes I saw the plus box but sometimes I didn’t. I didn’t know if it meant I needed to do something like scan more.” P9 suggested the app to “show a progress bar during the scan process. I felt a little lost as to if it was done scanning or not." Overall, the app needs to provide more support by implementing “more words, buttons, and tutorials so I know what to do and when I did something wrong,” as P3 mentioned, “so we don’t have to remember these details.” P3 drew an example for a potential iteration (Figure 11).

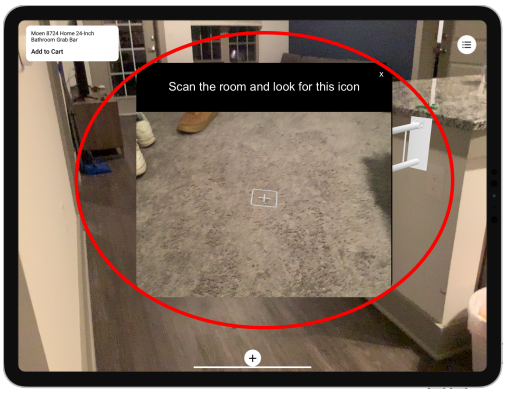


Figure 11 – Tutorial suggestions for future UI iterations

CHAPTER 5. DISCUSSION OF FINDINGS

5.1 Importance of AR in OT Practice

In this study, OTs viewed the AR tool as being important and useful at providing visuals for their AT recommendations during home modification sessions. This is particularly useful, as almost 30% of purchased ATs end up being unused or abandoned due to lack of fit to the home environment or lack of involvement from the PwIDs (Betsy, 1999; Cumming, 1999). Without such proper ATs, PwIDs may experience a decrease in their sense of independence at home and thereby a decrease in their sense of control and quality of life as well (Money, 2009).

Our study has shown that AR can involve the context of the home environment and increase the visibility of how various ATs may fit in the specific context. Although the existing methods of showing Amazon pictures to suggest ATs cannot provide a full understanding of their sizes and fits, our AR tool can superimpose ATs over a given environment such as a bathroom or bedroom to provide the visuals of how the ATs may look in that context. Currently, as two participants mentioned, many ATs such as tub benches are abandoned because PwIDs and their family members purchase ones that do not fit into their own bathroom. This is costly as they need to purchase new ones and invite OTs again for additional home visits. With the AR tool, all the participants expressed AR's potential to reduce such mistakes and AT abandonment by providing the exact visuals of the ATs on top of home environments such as a bathroom, which

provides much more clarity and information than to showing 2D images from the Internet. This aligns with the study by Bianco et al. (2016) who has revealed the importance of placing ATs in the context to understand the overall fit in the context. Several OTs even found AR to be more useful than having physical demo devices, as it is impractical for OTs to borrow or purchase and bring an immense range of various ATs to all of their home modification sessions. Here, OTs are able to demonstrate any ATs with multiple options per an AT and use the visuals with a tablet that most of them already bring to their sessions. This is new compared to the AR prototype built by Bianco et al. (2016) and AR software built by Luo (2015), as both focused on showing one type of AT rather than supporting OTs and PwIDs with a diverse range of options. Overall, all participants mentioned that the AR tool will make them more confident to provide concrete suggestions and as well as decrease the likelihood of AT abandonment, because both OTs and PwIDs can foresee how the suggested ATs will look in the context in real-time.

OTs also perceived that AR can involve the PwIDs to have more power over the selection and purchase of ATs. Currently, several participants mentioned that PwIDs may not understand the purpose of ATs and feel unmotivated to give inputs, or worse, not follow through with the suggestions. In fact, a study done in Loughborough University revealed that working together with PwIDs to understand their needs and find or develop ATs has increased PwIDs satisfaction toward the ATs and likelihood in purchasing them (Ariadi, 2012). The majority of the participants found the ability of AR to promote a patient-centered approach, where they can place complex ATs such as bedside commode

on top of PwID's bed to work together with the PwIDs, see the actual ATs in their context, and visually understand their benefit. This is particularly useful, because participants mention that pictures on Amazon are not PwIDs' home settings so PwIDs do not understand why they need to purchase such ATs and how they will improve the quality of life. Here, because the AR tool is on a tablet, OTs can hand the iPad to the PwIDs for them to freely look at the ATs placed in AR from all angles to visually digest their purposes. PwIDs are also able to place multiple ATs side by side or replace an AT with another from a variety of options. Several participants mentioned that comparing 3D grab bars side by side on the actual wall in AR is much more interactive and compelling than comparing 2D images of two grab bars. This is particularly useful, as surprisingly many participants mentioned that PwIDs care about how the ATs would affect the look and feel of their home environment, so being able to compare and choose in the context is important for their aesthetic considerations. This aligns with the outcome from the VR project by Ventä-Olkkonen (2014), as people appreciated VR's ability to see furniture and easily place them anywhere. However, VR requires a VR headset that can only be worn by one person and utilizes a template of a fake home environment. On the contrary, AR can place ATs anywhere in PwIDs' actual home environments for both PwIDs and their family members to visualize their overall environment with ATs to maintain the aesthetics of their home. All participants mentioned that AR will certainly excite PwIDs and make them feel more ownership over picking ATs for their own homes, which supports OT's belief of being patient-centered and results in higher buy-in from PwIDs.

5.2 Limitation and Opportunities of Remote User Study for AR Tool

As mentioned, more than half of our user study was conducted remotely due to the situation from coronavirus. Remote user study is uncommon for AR, and we initially have considered simply video calling participants and having them see us use the AR tool through screen share method. However, to test AR tools properly, participants needed to demo in their own rooms and place ATs on their own walls instead of watching us placing ATs on our wall. Hence, we have shipped the iPad with our AR tool installed to participants to try it themselves during the user study. The major limitation of this remote user study method is that many participants forgot that they are video calling and left to other rooms such as their kitchens or bathrooms to try AR which prevented us from hearing more about their thoughts and insights in real-time. In the future, it is possible to have both the video call and AR tool on the iPad so we can see and hear what they are doing in real-time. Overall, because the results from the remote studies provided equal amounts of insights than from face-to-face studies, any other AR projects out there can try remote as well and test with more participants around the world. In fact, we argue that conducting remote studies can provide opportunities for participants to try out AR in their familiar and relevant environment such as their home, which can potentially contribute to more insights and more valid results in comparison to usability labs.

5.3 Usability of the Tool and Requirements for Future Design

Most of the participants in this study struggled to use the AR tool, either in the AR scanning or in the AR interaction or both, thus requiring the tool to provide additional

focus on tutorials for the majority of OTs who are not quite experienced with technology in practice. For AR scanning, several participants did not know when the scanning was finished and were confused when they weren't able to place an AT in AR. So, future iteration of the AR tool should provide a tutorial in the beginning to virtually guide the OTs to point the tablet to a surface and slowly move across, as well as provide a progress bar that clearly indicates if they are done with scanning or not. For AR interaction, the AR tool assumed the common gestures on tablets to use two fingers for rotation and hold with one finger to move ATs around. Although the presence of buttons may disrupt the AR experience by taking up space on the interface, several participants mentioned that they prefer buttons due to clarity and familiarity with the feature. Future iteration of the AR tool should provide 2D buttons with clear text for interactions with the AR, including but not limited to move, lock, rotate, delete, replace, and add new.

Conversely, all participants in this study found the overall experience to be smooth despite some struggles with AR and concluded that they would use the tool if it was available on their tablets. We believe, the iterative process of designing this tool, (semi-structured interviews and codesign sessions with OTs) enabled us to fully understand OTs current method and their specific pain points, resulting in a satisfactory product. For instance, all participants were successfully able to navigate the browse section and find and choose an AT easily and smoothly. The browse experience was codesigned with actual OTs and iterated based on their feedback. In addition, all participants found the add to cart feature to be crucial to involve PwIDs and their family members even after the session so they can review and purchase the suggested ATs with

ease. This feature is also the result of the codesign session, where both participants drew out and discussed a shopping cart feature with the ability to email the list.

The participants also found the screenshot feature useful because they can email the screenshots of the visuals from AR to PwIDs, their family members, or their caretakers as reference for when they are installing the ATs later. Overall, our AR tool produced positive user experience because it involved consideration of all steps that OTs take and all frustrations that they have during their home modification sessions.

CHAPTER 6. CONCLUSION

6.1 Conclusion

In this project, we codesigned, developed, and evaluated a tablet-based AR application for use by OTs in home care. This application allowed OTs to support individuals with physical impairment and disability when making home modifications. The findings from the user study revealed that OTs perceived the use of AR in practice beneficial because it would provide more visual context to improve finding the most fitting ATs for PwIDs' home environment and the collaboration between PwIDs and their family. For suggesting ATs, OTs currently rely on paper printouts and online images of ATs, which can lead PwIDs making purchases that do not fit the home environment. They also rely on demo devices that they do not have constant access to a diverse range of ATs. With AR, OTs can superimpose 3D models of ATs onto the home environment in real-time to envision the home modification plans for purchasing and utilizing ATs in PwID's homes. This can increase the likelihood that the ATs will fit PwIDs' needs and their home environment and decrease the likelihood that the ATs will end up unused or abandoned. Because ATs are crucial to guide PwIDs to increase their independence and improve their quality of life, participants mentioned that they will immediately use the tool to enhance their current process to provide more optimal and people-centered care for PwIDs.

6.2 Limitation of Study

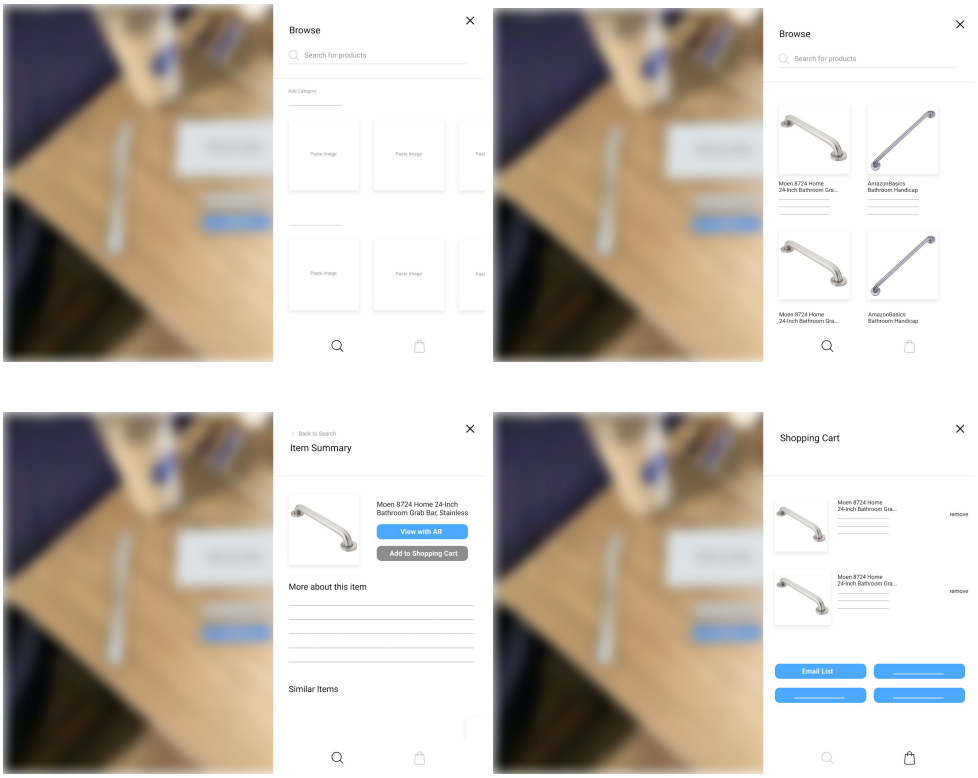
Majority of our user study was conducted with OTs in their work settings without PwIDs being present. It was difficult to find pairs of OTs and PwIDs, and we have decided to conduct the user study with only OTs because the tool is primarily built for them. However, future research can include PwIDs in the study to observe how the AR tool will change the way OTs suggest ATs to PwIDs in a real OT session setting. In addition, due to COVID-19 and practice of social distancing, the majority of our user study was conducted through video calls remotely. Although we supported our participants' first-hand experience with the AR tool by sending them the tablet in advance, it was difficult to encourage more think-aloud sessions because several participants got excited by the AR technology and walked off to it in other rooms such as their bathroom or kitchen. However, all participants also mentioned that because they have performed the AR tool remotely through video call, they indicated its potential to open up home modification sessions with PwIDs remotely by asking them to scan the room and try off-the-shelf ATs themselves while OTs observe the tablet screen and provide suggestions. In further studies, we can consider the implementation of Apple's Switch Control feature, whereby OTs can not only observe the tablet screen but also control it to search for ATs and remotely place them in the AR.

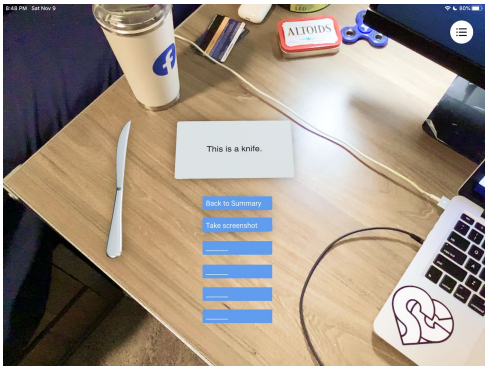
6.3 Future Iteration

Future iterations of the AR tool include additional features that support specific OT processes. Several participants requested a feature that would enable them to scan objects, such as a toilet, to get dimensions because this would be useful to narrowing

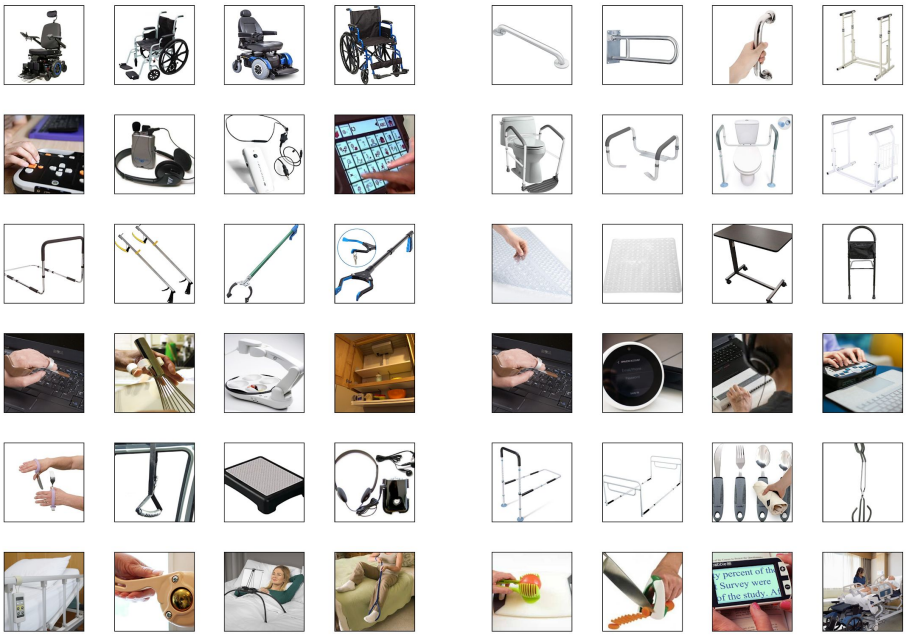
down the search for ATs by understanding the given space. This would need to look into ARPlaneAnchor under ARKit3 to pick two points and calculate the distance, as well as Swift UIKit to display and store such information. Other OTs requested a feature to customize ATs in AR. For example, OTs may want to modify a reaching tool to have a specialized grip on its end for PwIDs with low grip strength. This requires further research into RealityKit and linking ARKit3 with a 3D modeling tool such as AutoCAD to be able to manipulate 3D models of given ATs. Finally, the majority of participants mentioned that ideally there are video tutorials for ATs so PwIDs not only see them in their environment but can also further understand their purpose and their usability. This requires animation tools such as Mixamo to create video tutorials using 3D models and import them onto the tool. Overall, these iterations will make the AR tool even more comprehensive to support and enhance the entire OT home modification process.

APPENDIX A. WORKSHOP MATERIALS



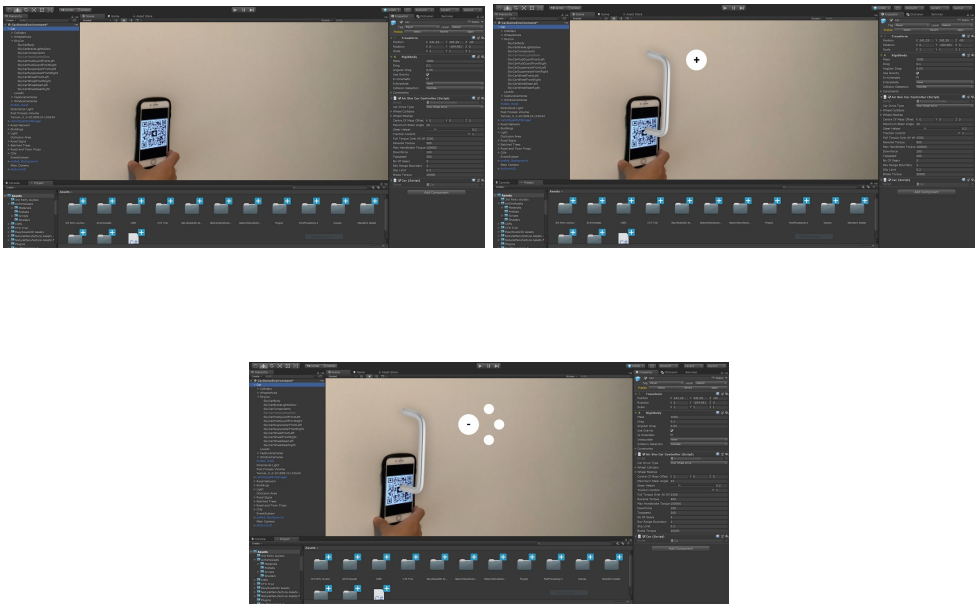


Template UI for codesign session: UI elements that need OTs' inputs are left blank to encourage them to write down or sketch their ideas.

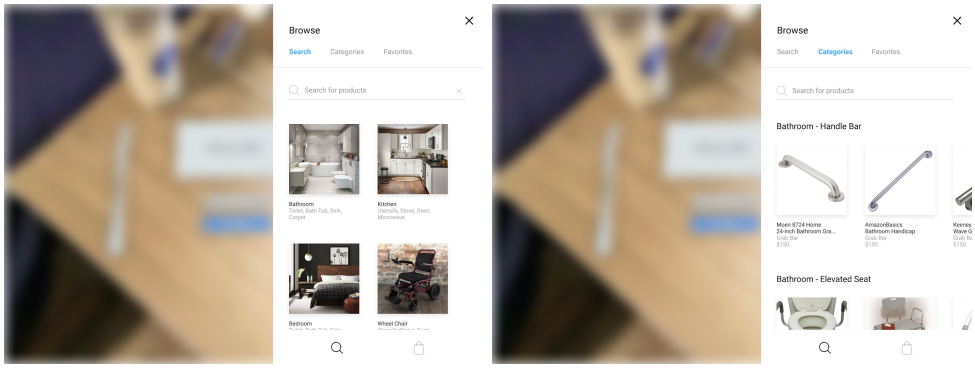


Sample pictures of ATs and home environment for OTs to place around in the UI templates to express ideas.

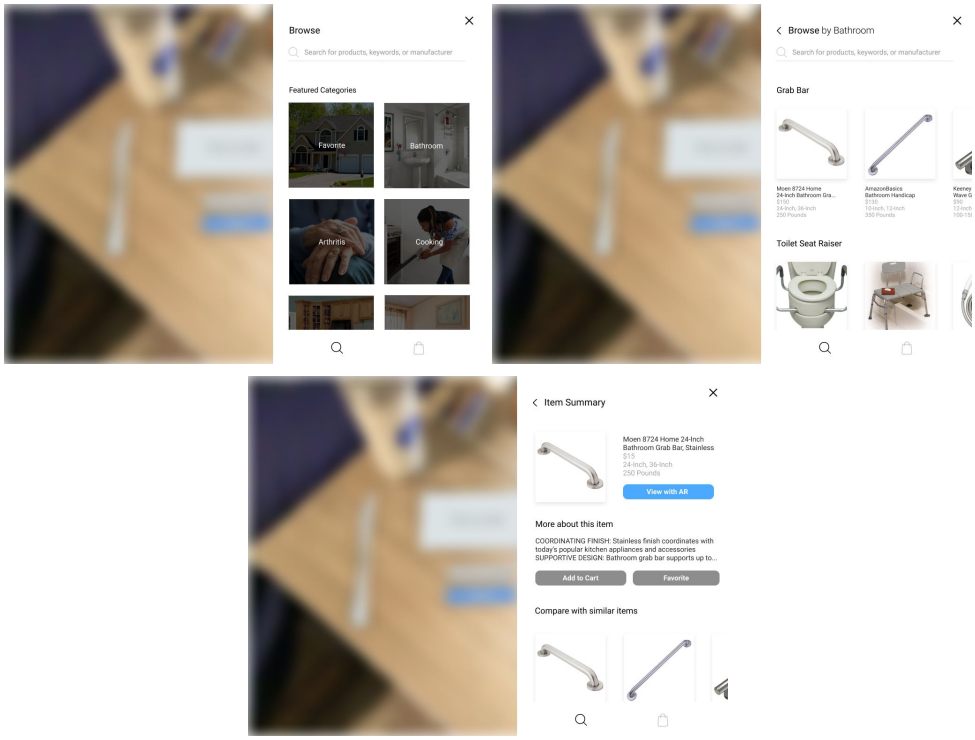
APPENDIX B. AR PROTOTYPE ITERATIONS



Initial prototype using Unity and Vuforia SDK



Prototype using Apple's ARKit3 and XCode and incorporating findings from semi-structured interviews



Final prototype incorporating findings from codesign session

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